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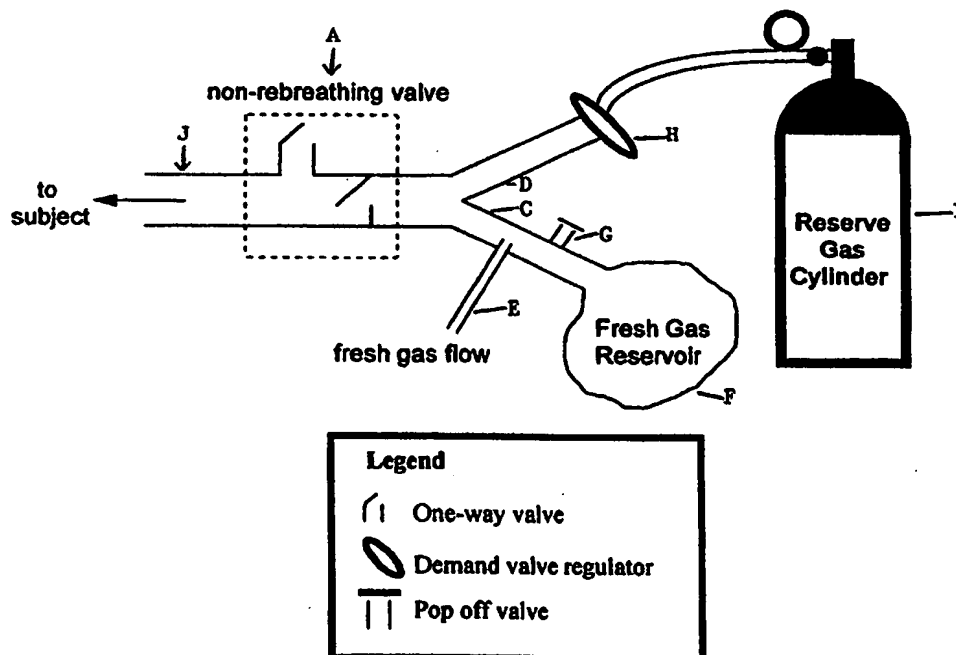
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(54) Title: ELIMINATION OF VAPOUR ANAESTHETICS FROM PATIENTS AFTER SURGICAL PROCEDURES



(57) Abstract

A method of treatment of an animal to recover from vapour anaesthetics administration is provided, the method comprising delivering to a patient gases which do not contain CO₂ at a specified rate, and gases containing CO₂ to maintain the same PCO₂ in the animal independent of the rate of ventilation, at the rate of ventilation of the animal which exceeds the rate of administration of the gases which do not contain CO₂.

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TITLE OF INVENTION

Elimination of vapour anaesthetics from patients after surgical procedures

FIELD OF INVENTION

5 The purpose of this invention is to provide a simple breathing circuit that can, for example, be added to a standard circle anaesthetic circuit known to persons skilled in the art to hasten recovery of patients administered vapour anaesthetics prior to an operation.

10 This invention also relates to the use of the breathing circuit in hastening the recovery of patients who have been administered vapour anaesthetics prior to a surgical operation.

 This invention also relates to methods of treatment of patients to hasten their recovery from administration of the vapour anaesthetics to them prior to surgical procedures.

15 BACKGROUND OF THE INVENTION

Physiology

20 Venous blood returns to the heart from the muscles and organs depleted of oxygen (O_2) and full of carbon dioxide (CO_2). Blood from various parts of the body is mixed in the heart (mixed venous blood) and pumped to the lungs. In the lungs the blood vessels break up into a net of small vessels surrounding tiny lung sacs (alveoli). The net of vessels surrounding the alveoli provides a large surface area for the exchange of gases by diffusion along their concentration gradients. A concentration gradient exists between the partial pressure of CO_2 (PCO_2) in the mixed

25 venous blood ($PvCO_2$) and the alveolar PCO_2 . The CO_2 diffuses into the alveoli from the mixed venous blood from the beginning of inspiration until an equilibrium is reached between the $PvCO_2$ and the alveolar PCO_2 at some time during the breath. When the subject exhales, the end of his exhalation is considered to have come from the alveoli and reflect the

30 equilibrium concentration between the capillaries and the alveoli; the PCO_2 in this gas is called end-tidal PCO_2 ($PETCO_2$).

 When the blood passes the alveoli and is pumped by the heart to the arteries it is known as the arterial PCO_2 ($PaCO_2$). The arterial blood has a PCO_2 equal to the PCO_2 at equilibrium between the capillaries and

35 alveoli. With each breath some CO_2 is eliminated and fresh air containing little CO_2 (assumed to be 0) is inhaled and dilutes the residual

alveolar PCO_2 , establishing a new gradient for CO_2 to diffuse out of the mixed venous blood into the alveoli. The rate of breathing, or ventilation (V), usually expressed in L/min, is exactly that required to eliminate the CO_2 brought to the lungs and maintain an equilibrium PCO_2 (and PaCO_2) of approximately 40 mmHg (in normal humans). When one produces more CO_2 (e.g. as a result of fever or exercise), more CO_2 is produced and carried to the lungs. One then has to breathe harder (hyperventilate) to wash out the extra CO_2 from the alveoli, and thus maintain the same equilibrium PaCO_2 . But if the CO_2 production stays normal, and one hyperventilates, then the PaCO_2 falls.

It is important to note that not all V contributes to blowing off CO_2 . Some V goes to the air passages (trachea and bronchi) and alveoli with little blood perfusing them, and thus doesn't contribute to blowing off CO_2 . That portion of V that goes to well perfused alveoli and participates in gas exchange is called the alveolar ventilation (VA).

There are a number of circumstances in therapeutic medicine and research where we want the subject to breathe harder but not change his PaCO_2 (see Table 1).

Table 1

Type of Investigation	Reference	Method of adjustment	Source of CO ₂
Respiratory muscle fatigue	5	M	R
	12	M	E
	7	M	R
Respiratory muscle training	2	M	R
	3	M	R
Increased V during anaesthesia	6	M	R
Carotid chemoreceptor function	8	M	E
	1	M	E
Effect of hypoxia on sympathetic response	10	M	E
	4	M	E
Control of respiration	9	A	E
Tracheobronchial tone	11	M	E

Table 1:

5 **Title:** Summary of previous studies attempting to maintain constant PETCO₂ during hyperpnea

Legend: Method of adjustment of inspired PCO₂ : M = manual; A = automated. Source of CO₂: R = rebreathing; E = external.

- 10 1. Angell-James, J.E., Clarke, J.A., de Burgh Daly, M. and Taton, A., Carotid chemoreceptor function and structure in the atherosclerotic rabbit: respiratory and cardiovascular responses to hyperoxia and hypercapnia. *Cardiovascular Research* 23(6): 541-53, 1989.
2. Belman, M.J. and C. Mittman. Ventilatory muscle training improves exercise capacity in chronic obstructive pulmonary disease patients. *Am. Rev. Respir. Dis.* 121:273-280, 1980.

3. Bradley, M.E. and Leith, D.E. Ventilatory muscle training and the oxygen cost of sustained hyperpnea. *J. Appl. Physiol.* 45(6):885-892, 1978.
4. Busija, D.W., Orr, J.A., Rankin, J.G.H., Liang, H.K. and Wagerle, L.C., Cerebral blood flow during normocapnic hyperoxia in the unanaesthetized pony. *J. Appl. Physiol.* 48(1):10-15, 1980.
5. Jonsson, L.O. Predictable PaCO₂ with two different flow settings using the Mapleson D. system. *Acta Anaesthesiol Scand.* 34:237-240, 1990.
- 10 6. McKerrow, C.B., and Otis, A.B. Oxygen cost of hyperventilation. *J. Appl. Physiol.* 9:375-79, 1956.
7. Robbins, P.A., Swanson, G.D. and Howson, M.G. A prediction-correction scheme for forcing alveolar gases along certain time courses. *J. Appl. Physiol.* 52(5):1353-1357, 1982.
- 15 8. Smith, D.M., Mercer, R.R. and Eldridge, F.L., Servo control of end-tidal CO₂ in paralyzed animals. *J. Appl. Physiol.* 45(1):133-136, 1978.
9. Somers, V.K., Mark, A.L., Zavala, D.C. and Abboud, F.M. Influence of ventilation of hypocapnia on sympathetic nerve responses to hypoxia in normal humans. *J. Appl. Physiol.* 67(5):2095-2100, 1989.
- 20 10. Sorkness, R. and Vidruk, E. Reflex effects of isocapnic changes in ventilation of tracheal tone in awake dogs. *Respir. Physiol.* 69:161-172, 1987.
11. Tenney, S.M. and Reese, R.E. The ability to sustain great breathing efforts. *Respir. Physiol.* 5:187-201, 1968.
- 25 12. Wahba, R.W.M. and Tessler, M.J. Misleading end-tidal CO₂ tensions. *Can. J. Anaesth.* 43(8):862-6, 1996.

30 This requires compensating for excess ventilation by inhaling CO₂ either from exhaled gas or some external source. The amount of CO₂ required to be inhaled needs to be adjusted manually or by an automated servo-controlled mechanism, depending on how fine the control of PaCO₂ is required. The input signal is the PETCO₂. Stability of PaCO₂ depends on the variability of CO₂ production and ventilation on the one hand, and the ability of a system to compensate for this variability on the other.

35 The termination of the anaesthetic effects of intravenously administered drugs depends on metabolism and redistribution. The

recovery time from anaesthesia is, therefore determined by the drug's pharmacology and cannot be accelerated.

- This is not so for inhaled anaesthetic vapours. The uptake and elimination of anaesthetic vapours is predominantly through the lungs.
- 5 The partial pressure of an anaesthetic vapour in the blood going to the brain is dependent upon the equilibration of vapour between the blood and the lungs. The concentration of vapour in the lungs in turn is dependent on the concentration of vapour in the inhaled gas, the rate of breathing, and the rate of transfer of gas between the lung and the blood.
- 10 The newer anaesthetic agents desflurane and sevoflurane have very low blood solubility. Therefore the amount of drug transferred between the lungs and the blood is small and can, for discussion purposes, be ignored. Thus, for a patient waking up from a vapour anaesthetic, the greater the rate of breathing, the more vapour is eliminated from the lungs.
- 15 However, in anaesthetized patients breathing spontaneously, ventilation is often depressed as a result of combined effects of residual intravenously administered anaesthetic drugs, pain relieving drugs (i.e. narcotics), the effects of surgery, as well as the respiratory depressant effect of the residual anaesthetic vapour itself
- 20 Practically, there has been limited scope for intervention to hasten the process of eliminating vapour from the lung and thus hastening the rate of emergence from the effects of vapour anaesthesia.

Proposals in Prior Art

1. Artificial ventilation
- 25 Manually or mechanically hyperventilating patients at the end of surgery is generally ineffective in shortening the time of recovery from anaesthesia.
- a) High ventilation using the circle anaesthetic circuit results in rebreathing of exhaled gases. These gases contain anaesthetic vapour as well as CO_2 . The CO_2 is eliminated by the CO_2 absorber in the circuit, but the exhaled anaesthetic vapour is returned to the patient.
- 30
- b) The attempts at hyperventilation will result in a decrease in arterial PCO_2 . The low arterial PCO_2 removes the stimulus to breathe, which in turn delays elimination of vapour (and may also prevent adequate oxygenation of the blood).
- 35

This is seldom practised.

2. Flushing the circuit:

High fresh gas flows in the circuit are inefficient in washing out the vapour from the circuits. The circle anaesthetic circuits have volumes of approximately 8 L (not counting the patient's lung volume of approximately 2.5 L). At the maximum fresh gas flows on the oxygen flow meter of 10 L/min, it would take about 4 minutes to wash out the anaesthetic vapour from the circuit alone!

3. Stimulate breathing

In the past, some anaesthetists tried to stimulate the patient's breathing by adding CO₂ to the breathing circuit. The rationale was to increase the CO₂ concentration in the circuit, stimulate the patient to breathe harder until he managed to ventilate off the CO₂ and some of the vapour as well. This has largely been abandoned and has been labeled a wasteful and dangerous practice.

a) It is wasteful for the reasons enumerated in 1a and 1b (vide supra). As well, the practice is wasteful in that extra CO₂ absorbing crystals are consumed.

b) The technique may put a patient at risk if the patient cannot respond to the extra CO₂ by increasing their ventilation. They will absorb it and develop a high blood CO₂ concentration which can be detrimental. The high CO₂ in the patient also causes them a good deal of distress on waking up as it makes them feel like they are not getting enough air to breathe.

4. Increase ventilation, keeping PCO₂ constant

To increase the ventilation without lowering PCO₂ requires adding CO₂ to the circuit. This can be supplied from an external source or from the subject's exhaled gas. All the presently described systems depend on a servo-controlled system, or feedback loop to regulate the amount of CO₂ supplied to the patient. These devices are complex, cumbersome and expensive. No such device has been reported used for hastening the elimination of anaesthetic vapour during recovery from anaesthesia.

With respect to 4 above, there are considerable limitations of servo-controlled methods, both manual or automatic. These may be discussed

as follows:

1. Input signal

Whereas the parameter that we want to keep constant is the arterial PCO_2 , feedback systems use the CO_2 concentration in the expired gas, the so called end tidal PCO_2 (PETCO_2) as the input signal and endpoint. The PETCO_2 can be very different from the arterial PCO_2 in many circumstances. Furthermore, changes in PETCO_2 may not correlate with those in arterial PCO_2 . This will result in PETCO_2 being an inappropriate input for the control of arterial PCO_2 . For example, a smaller than usual breath *decreases* PETCO_2 (tending to *increase* arterial PCO_2), causing a servo-controller to respond with an inappropriate *increase* in inspired CO_2 .

2. Gain

If, in an attempt to obtain fine control, the gain in a servo-control system is set too high, the response becomes unstable and may result in oscillation of the control variable. Conversely, if the gain is set too low, compensation lags. Over-damping of the signal results in a the response never reaching the target. To address these problems, servo-controllers require complex algorithms and expensive equipment.

3. Inherent limitation

Servo-control systems work on the principle of detecting, and subsequently attempting to correct for, changes in PETCO_2 . Even under ideal conditions, no such system can predict the size of an impending VT in a spontaneously breathing subject and thus deliver the appropriate CO_2 load.

As is apparent, people have tried to hasten the recovery of patients who have been anaesthetized and have made substantial efforts in this regard. However, they have been, for the most part, as seen above, unsuccessful. The reason for the attempts is that the benefits of faster return to consciousness, the less the need for recovery care and the less risk of nausea and post-operative respiratory complications. Thus the health care system will save substantial dollars. In this regard, the cost to the health care system of operating room and recovery area time is approximately \$5.00 (Canadian Dollars) and \$2.00 (Canadian Dollars) per minute respectively. The total number of anaesthetics given in North

America is approximately 35,000,000/year (3.5 million and about 30 million in the United States), a conservative estimate with as high as about 50,000,000/year. The North American estimate does not include Mexico or countries in Central America. A modest average decrease in recovery time in the operating time and in the recovery room of 5 minutes each can potentially result in billions of dollars savings per year worldwide. In North America alone, the expectation of saving 5 minutes in each of the operating room and recovery area can amount to \$1,000,000,000 in savings.

It is therefore an object of this invention to provide an improved breathing circuit or circuit components that can be added to a standard circle anaesthetic circuit to be used to hasten recovery of patients who have been administered vapour anaesthetics.

It is a further object of the invention to provide methods of treatment using the said circuit and the use of the said circuit during the administration of vapour anaesthetics to hasten recovery of the said patients.

Further and other objects of the invention will be realized by those skilled in the art reading the following summary of the invention and detailed description of embodiments thereof.

SUMMARY OF THE INVENTION

According to one aspect of the invention, there is provided a new breathing circuit and components thereof that can, for example, be added to a standard circle anaesthetic circuit for hastening the recovery of patients administered vapour anaesthetics.

In accordance with the invention, the said circuit and components thereof, when combined with the general anaesthetic circle circuit cause the administration of carbon dioxide gas to the patient to maintain the same PCO_2 in the patient independent of the rate of ventilation (so long as the said rate of ventilation is greater than a control rate of ventilation) but permit the rate of anaesthetic vapour elimination from the lungs of the patient to vary directly as the total ventilation by the patient, whether the patient is breathing normally or is hyperventilating. Thus, the vapour anaesthetic is eliminated from the lungs. However, the carbon dioxide is not eliminated from the lungs at a rate greater than the resting rate of the patient or a predetermined control rate. (The predetermined rate of

elimination of CO₂ may be set based on the rate of administration of the fresh gas into the circuit as discussed below.)

Thus, according to another aspect of the invention, the simple breathing circuit comprises components which together form the simple circuit and comprise (a) an exit port from which the gases exit from the circuit to the patient, (b) a non-rebreathing valve which constitutes a one-way valve permitting gases to be delivered to the exit port to be delivered to the patient but which non-breathing valve when the patient breathes into the exit port does not permit the gases to pass the non-rebreathing valve into the portion of the circuit from which the gases are delivered but passes them to ambient or elsewhere, (c) a source of gas (which may be oxygen or air or other gases but does not contain CO₂ (air contains physiologically insignificant amounts of CO₂) in communication with the non-breathing valve to be delivered through the valve to the patient, (d) a fresh gas reservoir in communication with the source of fresh gas flow for receiving excess gas not breathed by the patient from the source of gas and for storing same and when the patient breathes and withdraws amounts of gas from the source of gas flow also enables the patient to receive gas from the fresh gas reservoir in which the gases have been stored, (e) a reserve gas supply containing CO₂ and other gases (usually oxygen) wherein the partial pressure of the CO₂ is approximately equal to the partial pressure of the CO₂ in the patient's mixed venous blood, for being delivered to the non-rebreathing valve as required by the patient to make up that amount of gas required by the patient when breathing that is not fulfilled from the gases delivered from the source of gas flow and fresh gas reservoir, the said source of gas and fresh gas reservoir and reserve gas supply being disposed on the side of the valve remote from the exit port.

Preferably a pressure relief valve is in communication with the fresh gas reservoir, in the event that the fresh gas reservoir overfills with gas so that the fresh gas reservoir does not break, rupture or become damaged in any way.

The reserve gas supply preferably includes a demand valve regulator so that where the additional gas is required, the demand valve regulator opens the communication of the reserve gas supply to the non-rebreathing valve for delivery of the gas to the non-breathing valve and where not required the demand valve regulator is closed and only fresh

gas flows from the source of fresh gas and from the fresh gas reservoir to the non-rebreathing valve. The source of fresh gas is set to supply fresh gas (non-CO₂-containing gas) at a rate equal to the desired alveolar ventilation for the elimination of CO₂.

5 The basic concept underlying my approach is that when breathing increases, the rate of flow of fresh gas (inspired PCO₂ = 0) from the fresh gas flow contributing to elimination of CO₂ is kept constant. The remainder of the gas inhaled by the subject (from the reserve gas supply) has a PCO₂ equal to that of mixed venous blood, does not contribute to a
10 CO₂ concentration gradient between mixed venous blood and alveolar gas, and thus does not contribute to elimination of CO₂. If there is access to mixed venous blood (such as if a catheter is present in the pulmonary artery, the mixed venous PCO₂ can be measured directly. If there is no possibility of measuring, then an estimation can be made from PETCO₂.
15 PETCO₂ is determined by measuring the PCO₂ of expired using a capnograph usually present or easily available in an operating facility by persons skilled in the art.

In effect, the device passively, precisely and continuously matches the amount of CO₂ breathed in by the patient to the amount of total
20 breathing, thereby preventing any perturbation of the arterial PCO₂. This is opposed to servo-controllers which are always attempting to compensate for changes. Persons skilled in the art, however, may automate the circuit by using a servo-controller or computer to monitor and deliver the amounts from the reserve gas supply.

25 According to another aspect of the invention, the new simple breathing circuit is used to treat a patient to enable the patient to recover more quickly from, and to hasten the recovery of the patient after, vapour anaesthetic administration.

30 According to another aspect of the invention, the use of the said circuit is made in the manufacture of a device to hasten the recovery of patients from administration of vapour anaesthetics.

According to another aspect of the invention, the use of the said circuit is made to hasten the recovery of patients from vapour anaesthetics administration.

35 According to another aspect of the invention, a method of treatment of an animal (for example, a person) is provided (such as to

enable such animal to recover from vapour anaesthetics administration), the method comprising delivering to a patient gases which do not contain CO₂ at a specified rate, and gases containing CO₂ to maintain the same PCO₂ in the animal independent of the rate of ventilation, at the rate of ventilation of the animal which exceeds the rate of administration of the gases which do not contain CO₂.

Therefore, when the rate of ventilation of the animal exceeds the rate of delivery to the animal of non-CO₂-containing gases inhaled by the animal, the CO₂-containing gases inhaled by the animal maintain the PCO₂ in the animal constant.

Thus, with respect to the use of the invention to eliminate anaesthetic vapour from the lungs, the total ventilation of combined gases which includes the CO₂-containing, and non-CO₂ containing, gases act to eliminate vapour from the lungs.

This circuit and methods of treatment can also be used for any circumstance where one wants to dissociate the minute ventilation from elimination of carbon dioxide such as respiratory muscle training, investigation of the role of pulmonary stretch receptors, tracheobronchial tone, expand the lung to prevent atelectasis, and control of respiration and other uses as would be understood by those skilled in the art.

The circuit and methods of treatment may also be used by deep sea divers and astronauts to eliminate nitrogen from the body. It can also be used to treat carbon monoxide poisoning under normal baric or hyper baric conditions. The fresh gas will contain 100% oxygen, and the reserve gas will contain approximately 6% CO₂ and approximately 94% oxygen. Neither the fresh gas nor the reserve gas supply will, in this case, contain nitrogen.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 illustrates schematically the nature of the simple breathing circuit and components which enable the patient to recover more quickly from vapour anaesthetics administration. The said device shown enables the PCO₂ to remain constant despite increase in minute ventilation which thereby permits faster elimination of the vapour anaesthetic.

Figure 2 illustrates schematically portions of a standard circle anaesthetic circuit generally known to persons skilled in the art.

Figure 3 illustrates schematically the simple breathing circuit in one

embodiment added to the portions of the circle anaesthetic circuit shown schematically in Figure 2, illustrating modifications of the circuit shown schematically in Figure 1 for use with the generally known circuit shown in Figure 2. (It would be clear to persons skilled in the art that depending upon the circuit used as the circle anaesthetic circuit, different modifications on the basic circuit shown in Figure 1 will be made.)

Figure 4A illustrates the structure shown in Figure 3, now combined with the general structure shown in Figure 2. (Figure 3 shows the modifications made specifically to the structure of Figure 1 to combine it with the structure in Figure 2 which is now shown in Figure 4A.)

Figures 4B and 4C illustrate schematically close up portions of one portion of the structure shown in Figure 4A in different positions.

Figure 5 graphs the VT (Tidal Volume) and PETCO₂.

Figure 6 graphs traces of airway PCO₂ and VT.

Figures 7A, 7B and 8A and 8B graphically depict changes in PaCO₂ and PETCO₂.

DETAILED DESCRIPTION OF EMBODIMENTS

The circuit (Figure 1) consists of a non-rebreathing valve (A) connected distally to two ports (C and D). The first port is connected in parallel to a source of fresh gas (E) (which does not contain CO₂) and a fresh gas reservoir (F). A one-way pressure relief valve (G) prevents overfilling of the reservoir (F) by venting excess fresh gas. The second port (D) is connected via a one-way valve (H), to a source of gas (containing CO₂) whose PCO₂ is equal approximately to that of the mixed venous PCO₂. We call this the "reserve gas" (I). Non-rebreathing valve A is connected to exit port J (from which the patient breathes).

Functional analysis of circuit maintaining constant PCO₂ with hyperventilation

When the minute ventilation "V" is *less than or equal* to the fresh gas flow "FGF" from (E), the subject inhales only fresh gas (non-CO₂-containing gas). When V *exceeds* FGF, the reservoir (F) containing fresh non-CO₂-containing gas empties first and the balance of inhaled gas is drawn from the reserve gas (I) which contains CO₂. The reserve gas is considered not to participate in CO₂ exchange ensuring that the actual ventilation provided is limited by FGF. If the rate of FGF is 5L/minute and the patient breathes at 5L/minute or less, then the patient will inhale

only non-CO₂-containing gas that comes from fresh gas flow sources (E and F). If minute ventilation exceeds FGF, the difference between minute ventilation and fresh gas flow is made up from gas from reserve gas (I) which contains CO₂ at a concentration that does not provide a gradient for elimination of CO₂ in the patient.

Application of circuit to anaesthesia circle circuit

The schematic of the standard anaesthetic circle circuit, spontaneous ventilation (Figure 2)

When the patient exhales, the inspiratory valve (1) closes, the expiratory valve (2) opens and gas flows through the corrugated tubing making up the expiratory limb of the circuit (3) into the rebreathing bag (4). When the rebreathing bag is full, the airway pressure-limiting (APL) valve (5) opens and the balance of expired gas exits through the APL valve into a gas scavenger (not shown). When the patient inhales, the negative pressure in the circuit closes the expiratory valve (2), opens the inspiratory valve (1), and directs gas to flow through the corrugated tube making up the inspiratory limb of the circuit (6). Inspiration draws all of the gas from the fresh gas hose (7) and makes up the balance of the volume of the breath by drawing gas from the rebreathing bag (4). The gas from the rebreathing bag contains expired gas with CO₂ in it. This CO₂ is extracted as the gas passes through the CO₂ absorber (8) and thus is delivered to the patient (P) without CO₂, (but still containing exhaled anaesthetic vapour, if any).

Modification of the circuit (Figure 3) to allow hyperventilation of patients under anaesthesia

The modified circuit consists of

1. a circuit which acts functionally like a standard self inflating bag (such as made by Laerdal) consisting of
 - a) a non rebreathing valve, such as valve #560200 made by Laerdal, that functions during spontaneous breathing as well as manually assisted breathing (9);
 - b) an expired gas manifold, such as the Expiratory Deviator #850500, to collect expired gas (10) and direct it to a gas scavenger system (not shown) or to the expiratory limb of the anaesthetic circuit (figure 4);
 - c) a self inflating bag (11) whose entrance is guarded by a one

- way valve directing gas into the self inflating bag (12).
2. a source of fresh gas, (i.e. not containing vapour) e.g. oxygen or oxygen plus nitrous oxide (13) with a flow meter (22).
 3. a manifold (14) with 4 ports:
 - 5 a) a port (15) for input of fresh gas (13);
 - b) a port (16) for a fresh gas reservoir bag (17);
 - c) a port to which is attached a one way inflow valve that opens when the pressure inside the manifold is 5cm H₂O less than atmospheric pressure, such as Livingston Health Care Services catalog part #9005, (18) (assuring that all of the fresh gas is utilized before opening);
 - 10 d) a bag of gas (19) whose PCO₂ is equal approximately to that of the mixed venous PCO₂ connected to inflow valve (18)(Alternatively, the valve and gas reservoir bag can be replaced by a demand regulator, such as Lifetronix MX91120012, similar to that used in SCUBA diving, and a cylinder of compressed gas);
 - 15 e) a port to which is attached a one way outflow valve (20), such as Livingston Health Care Services catalog part #9005, that allows release of gas from the manifold to atmosphere when the pressure in the manifold is greater than 5cm H₂O.

Method of operation in an anaesthetic circuit (Figure 4A)

The distal end of the nonrebreathing valve (Laerdal type) (9), is attached to the patient.

- 25 The proximal port of the nonrebreathing valve is attached to a 3 way respiratory valve (21) which can direct inspiratory gas either from the circle anaesthetic circuit (Figure 4B) or from the new circuit (Figure 4C). The expiratory manifold (10) of the self inflating bag's non rebreathing valve is attached to the expiratory limb of the anaesthetic circuit (3).
- 30 Regardless of the source of inspired gas, exhalation is directed into the expiratory limb of the anaesthetic circuit.

To maximize the elimination of anaesthetic vapour from the patient's lungs, the 3-way respiratory stopcock is turned such that patient inspiration is from the new circuit (Figure 4C). Thus inspired gas from

35 the very first breath after turning the 3-way valve onward contains no vapour, providing the maximum gradient for anaesthetic vapour

elimination.

An increased breathing rate will further enhance the elimination of vapour from the lung. If breathing spontaneously, the patient can be stimulated to increase his minute ventilation by lowering the FGF (22) thereby allowing the PCO_2 to rise. Using this approach the PCO_2 will rise and plateau independent of the rate of breathing, resulting in a constant breathing stimulus. All of the ventilation is effective in eliminating vapour.

If the patient is undergoing controlled ventilation, he can also be hyperventilated with the self-inflating bag (11). In either case, the patient's PCO_2 will be determined by the FGF (22). As long as the FGF remains constant, the PCO_2 will remain constant independent of the minute ventilation.

To illustrate the effectiveness of the circuit we performed a number of tests with respect to humans and dogs. The humans were breathing spontaneously and the dogs were mechanically ventilated.

Human subjects

After obtaining institutional ethics board approval and informed consent, four healthy subjects aged 19 - 25 y breathed through the circuit by means of a mouth piece while wearing nose clips. During normal breathing, the FGF was set equal to V by adjusting the FGF such that the bag containing fresh gas just emptied at the end of each inhalation. Subjects were then instructed to breathe maximally ("breathe as hard as you can") for 3 min. Flows were recorded by means of a Pitot tube (Voltek Enterprises, Willowdale Canada) and the signal integrated to obtain volume. CO_2 was sampled continuously at the mouthpiece (Medical Gas Analyzer LB-2, Sensormedics Corp., Anaheim California). Analog signals were digitized at $60 \text{ samples} \cdot \text{s}^{-1}$ and recorded using data acquisition software (WINDAQ/200, DATAQ instruments, Inc. Akron Ohio).

Studies in dogs

Following institutional ethics board approval, 6 mongrel dogs of either sex weighing 20-25kg were anaesthetized with methohexital ($5\text{-}7 \text{ mg} \cdot \text{kg}^{-1}$ for induction followed by $150\text{-}300 \text{ mg} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) and intubated. Adequacy of anaesthetic depth was deduced from the eye lash reflex, lack of spontaneous movements, and stable heart rate and blood pressure. A catheter was placed in the femoral artery for monitoring blood pressure

and periodic sampling of blood for gas analysis. The dogs were ventilated with a conventional mechanical piston ventilator (Harvard Apparatus model 618, South Natick, MA). For each dog, an inflation volume (VT) of 400 ml and a frequency (f) of 10 min⁻¹ (duty cycle, 0.5) were used. All dogs were ventilated to just below their apneic thresholds (by increasing VT about 50 mL) so that they made no respiratory efforts. Tidal CO₂ was sampled continuously (Ametek, Thermox Instruments Division, Pittsburgh, PA) at the proximal end of the endotracheal tube. Flow was measured with a pneumotachograph (Vertek series 47303A, Hewlett-Packard) and the signal integrated to obtain volume. Analog signals were digitized at 17 samples·s⁻¹ and recorded using the same data acquisition software as that used in studies on human subjects.

Because of differences in initial PaCO₂s among dogs (reflecting individual sensitivities to CO₂, differences in anaesthetic levels, or differences in VT/body weight ratio), the CO₂ concentration in the reserve gas was arbitrarily adjusted for each dog to 1.5 ± 0.5% above its FetCO₂ to approximate the mixed venous PCO₂ (PvCO₂) (see Table II). To allow greater flexibility in setting the concentration of CO₂ in the reserve gas, the circuit was modified by replacing the demand valve with a one-way PEEP (positive end expiratory pressure) valve and the cylinder with a bag containing premixed gas. This circuit is functionally identical to that used in studies on humans. The circuit was connected to the intake port of the ventilator. Under control conditions, FGF was adjusted so that the fresh gas reservoir just emptied during each ventilator cycle; this end point was confirmed by a slight rise in FICO₂ above zero. After a steady-state had been reached (difference < 1.5 mm Hg in two successive PaCO₂'s taken 5 minutes apart), VT was increased at 5 minute intervals from 400 to 600 to 900 to 1200 mL. In a second trial at a fixed VT (approximately 400 mL) and fixed FGF, f was increased at 5 minute intervals from 10 to 14 to 18 to 22 min⁻¹. A blood sample for the determination of blood gases was drawn from the femoral artery at the beginning and end of each 5 min interval.

All data are expressed as means ± standard deviation. We tested for significant differences using one- or two-way ANOVA with post hoc analysis where appropriate. A p value less than 0.05 was considered significant.

Results:*Human subjects*

Figure 5 presents the VT and PETCO₂ of subject 1 during 3 min of maximal ventilatory effort. Results for all subjects are summarized in Table III; data represent average values for 10 breaths at 0 (the onset of hyperventilation), 1.5 and 3 min. PETCO₂ did not change significantly from control values throughout the course of hyperventilation ($p = 0.08$, ANOVA). There was considerable variability in V and breathing patterns between subjects but individual subjects tended to sustain a particular breathing pattern throughout the run.

Dogs

Figure 6 presents traces of airway PCO₂ and VT for dog #5 during changes in f or VT. Figures 7 and 8 show the changes in PaCO₂ and the PETCO₂ in all dogs during changes in f or VT. Increases in f did not significantly affect mean PaCO₂ or PETCO₂ ($p=0.28$ and $p=0.11$, respectively; ANOVA). Increases in VT decreased mean PaCO₂ from control only at VT of 1200 mL ($p=0.01$); in contrast, changes in VT did not affect mean PETCO₂ ($p=0.25$). The mean absolute change in PaCO₂ between control and the highest ventilation was 2.2 ± 1.8 mmHg (range 0.4 to 4.8) for f and 3.4 ± 2.3 mmHg (range 0.4 to 5.6) for VT.

COMMENTARY

The system minimized decreases in PETCO₂ over a wide range of ventilation (56 to 131 L min⁻¹) and breathing patterns, in hyperventilating human subjects and in mechanically hyperventilated dogs (4 to 12 L min⁻¹). The variability in PaCO₂ in the hyperventilated dogs, although small, may have been due to a) imprecise matching of reserve gas PCO₂ to the dog's PvCO₂s; b) prolonged duration of the maneuver in dogs (> 15 min versus 3 min for human subjects) and c) the extent of hyperventilation (see below). In addition, the different levels of ventilation may have induced changes in systemic and pulmonary blood flow (ventilation-perfusion matching, physiological and anatomical dead space), thereby affecting PaCO₂ and PvCO₂. Despite these sources of variability, the range over which PaCO₂ varied in my studies in dogs was similar to those reported in studies utilizing more complex equipment (see Table 1).

Conventional servo-controlled techniques designed to prevent

changes in PCO_2 with hyperpnea are less affected by changes in CO_2 production than the circuit; however, they have other limitations. The assumption that detected changes in $PETCO_2$ are due to a change in $PaCO_2$ is not always warranted (14). Small changes in ventilatory pattern can 'uncouple' $PETCO_2$ from $PaCO_2$, resulting in $PETCO_2$ being an inappropriate input for the control of $PaCO_2$. For example, a smaller VT decreases VA (which tends to increase $PaCO_2$) but will also decrease $PETCO_2$, causing a servo-controller to respond with an inappropriate increase in inspired CO_2 . Even under ideal conditions, a servo-controlled system attempting to correct for changes in $PETCO_2$ cannot predict the size of an impending VT in a spontaneously breathing subject and thus deliver the appropriate CO_2 load. If in an attempt to obtain fine control the gain in a servo-control system is set too high, the response becomes unstable and may result in oscillation of the control variable (11). Conversely, if the gain is set too low, compensation lags (9). Over-damping of the signal results in a the response never reaching the target. To address these problems, servo-controllers require complex algorithms (16) and expensive equipment.

When CO_2 production is constant, the circuit has the theoretical advantage over servo-controlled systems in that it provides passive compensation for changes in V. This minimizes changes in VA, preempting the need for subsequent compensation. Maintenance of a nearly constant VA occurs even during irregular breathing, including brief periods when V is less than the FGF. Under this circumstance, excess FGF is stored in the fresh gas reservoir and subsequently contributes to VA when ventilation exceeds FGF.

When CO_2 production increases during hyperventilation, as would occur with increased work of breathing or exercise, my method requires modification. To compensate, additional VA can be provided either by increasing FGF or by lowering the PCO_2 of the reserve gas below the $PvCO_2$, as expressed in the following equation:

$$VA = FGF + (V - FGF) (PvCO_2 - \text{reserve gas } PCO_2)$$

Because spontaneously breathing subjects had such variable V during hyperventilation, compensating for the CO_2 production by modifying FGF would have required constant adjustment. We therefore chose to decrease the PCO_2 of the reserve gas to establish a concentration

gradient between the PCO_2 of the reserve gas and the PvCO_2 ; when this gradient is constant, VA is a function of V . We found that, over the wide range of V exhibited by the subjects, a concentration of 5.5% CO_2 in the reserve gas (instead of 6.5% which corresponds to a PvCO_2 of 46 mmHg) provided the optimal gradient to compensate for increases in CO_2 production resulting from increased work of breathing.

I therefore have described a simple circuit that disassociates VA from V . It passively minimizes increases in VA that would normally accompany hyperventilation when CO_2 production is constant. It can be modified to compensate for increases in CO_2 production. The circuit may form the basis for a simple and inexpensive alternative to servo-controlled systems for research and may have therapeutic applications.

TABLE II

Dog #	Weight (kg)	Initial FETCO_2 (%)	Bag FCO_2 (%)
1	22	5.3	7.0
2	20	4.6	6.6
3	20	7.1	9.0
4	24	7.3	9.0
5	25	5.5	6.9
6	20	6.0	7.2

TABLE III

End Tidal PCO ₂ (mmHg)					Frequency (min ⁻¹)			
Time Subject #	Control	0	1.5	3	Time Subject #	0	1.5	3
1	40.3	33.6	34.9	35.6	1	57	50	47
2	36.6	30.9	28.1	28.0	2	89	87	88
3	42.0	42.5	43.2	42.7	3	31	30	30
4	41.0	34.5	38.8	38.8	4	149	130	127

Tidal Volume (L)				Minute Ventilation (L·min ⁻¹)			
Time Subject #	0	1.5	3	Time Subject #	0	1.5	3
1	2.30	2.49	2.58	1	131	124	118
2	0.85	0.72	0.63	2	75	63	56
3	2.60	2.64	2.26	3	80	78	68
4	0.78	0.62	0.60	4	117	80	76

- 5 While the foregoing provides a detailed description of a preferred embodiment of the invention, it is to be understood that this description is illustrative only of the principles of the invention and not limitative. Furthermore, as many changes can be made to the invention without departing from the scope of the invention, it is intended that all material
- 10 contained herein be interpreted as illustrative of the invention and not in a limiting sense.

THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE
PROPERTY OR PRIVILEGE IS CLAIMED ARE AS FOLLOWS:

1. A breathing circuit and components thereof for causing the administration of carbon dioxide gas to the patient to maintain the same PCO_2 in the patient independent of the rate of ventilation (so long as the said rate of ventilation is greater than a control rate of ventilation).
2. The circuit of claim 1 wherein the circuit permits the rate of anaesthetic vapour elimination from the lungs of the patient to vary directly as the total ventilation by the patient, whether the patient is breathing normally or is hyperventilating.
3. The circuit of claim 1 wherein the circuit permits the rate of nitrogen elimination from the lungs of the patient to vary directly as the total ventilation by the patient, whether the patient is breathing normally or is hyperventilating.
4. A breathing circuit comprises components which together form the simple circuit and comprise (a) an exit port from which the gases exit from the circuit to the patient, (b) a non-rebreathing valve which constitutes a one-way valve permitting gases to be delivered to the exit port to be delivered to the patient but which non-breathing valve when the patient breathes into the exit port does not permit the gases to pass the non-rebreathing valve into the portion of the circuit from which the gases are delivered but passes them to ambient or elsewhere, (c) a source of gas (which may be oxygen or air or other gases but does not contain CO_2 in communication with the non-breathing valve to be delivered through the valve to the patient, (d) a fresh gas reservoir in communication with the source of fresh gas flow for receiving excess gas not breathed by the patient from the source of gas and for storing same and when the patient breathes and withdraws amounts of gas from the source of gas flow also enables the patient to receive gas from the fresh gas reservoir in which the gases have been stored, (e) a reserve gas supply containing CO_2 and other gases wherein the partial pressure of the CO_2 is approximately equal to the partial pressure of the CO_2 in the patient's mixed venous blood, for being

delivered to the non-rebreathing valve as required by the patient to make up that amount of gas required by the patient when breathing that is not fulfilled from the gases delivered from the source of gas flow and fresh gas reservoir, the said source of gas and fresh gas reservoir and reserve gas supply being disposed on the side of the valve remote from the exit port.

5. The circuit of claim 4 further comprising a pressure relief valve is in communication with the fresh gas reservoir, in the event that the fresh gas reservoir overfills with gas so that the fresh gas reservoir does not break, rupture or become damaged in any way.

6. The circuit of claim 4 or 5 wherein the reserve gas supply includes a demand valve regulator so that where the additional gas is required, the demand valve regulator opens the communication of the reserve gas supply to the non-rebreathing valve for delivery of the gas to the non-rebreathing valve and where not required the demand valve regulator is closed and only fresh gas flows from the source of fresh gas and from the fresh gas reservoir to the non-rebreathing valve.

7. The use of the circuit of claim 1, 2, 3, 4, 5 or 6 is made in the manufacture of a device to hasten the recovery of patients from administration of vapour anaesthetics.

8. The use of the circuit of claim 1, 2, 3, 4, 5 or 6 to hasten the recovery of patients from vapour anaesthetics administration.

9. A method of treatment of an animal to recover from vapour anaesthetics administration, the method comprising delivering to a patient gases which do not contain CO_2 at a specified rate, and gases containing CO_2 to maintain the same PCO_2 in the animal independent of the rate of ventilation, at the rate of ventilation of the animal which exceeds the rate of administration of the gases which do not contain CO_2 .

10. The method of claim 9 wherein the animal is a person.

11. The method of claim 9 or 10 wherein the animal is enabled to

recover from vapour anaesthetics administration, the method comprising delivering to a patient gases which do not contain CO_2 at a specified rate, and gases containing CO_2 to maintain the same PCO_2 in the animal independent of the rate of ventilation, at the rate of ventilation of the animal which exceeds the rate of administration of the gases which do not contain CO_2 .

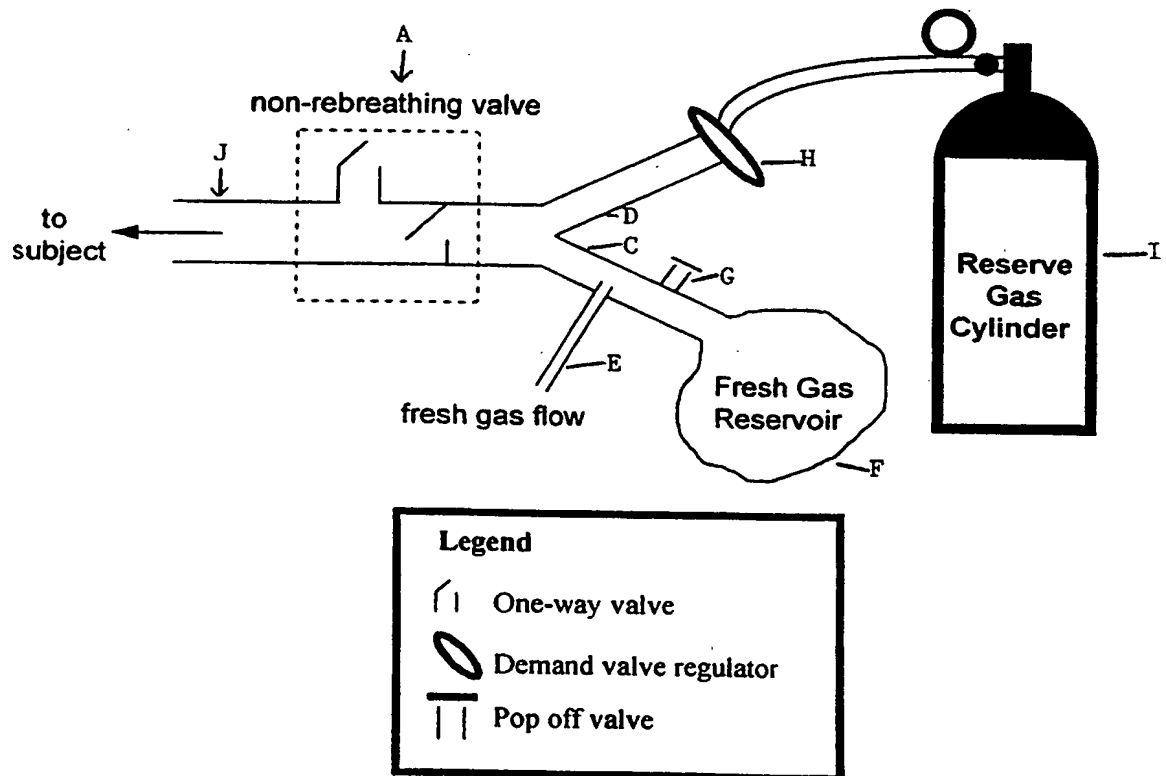


FIG. 1

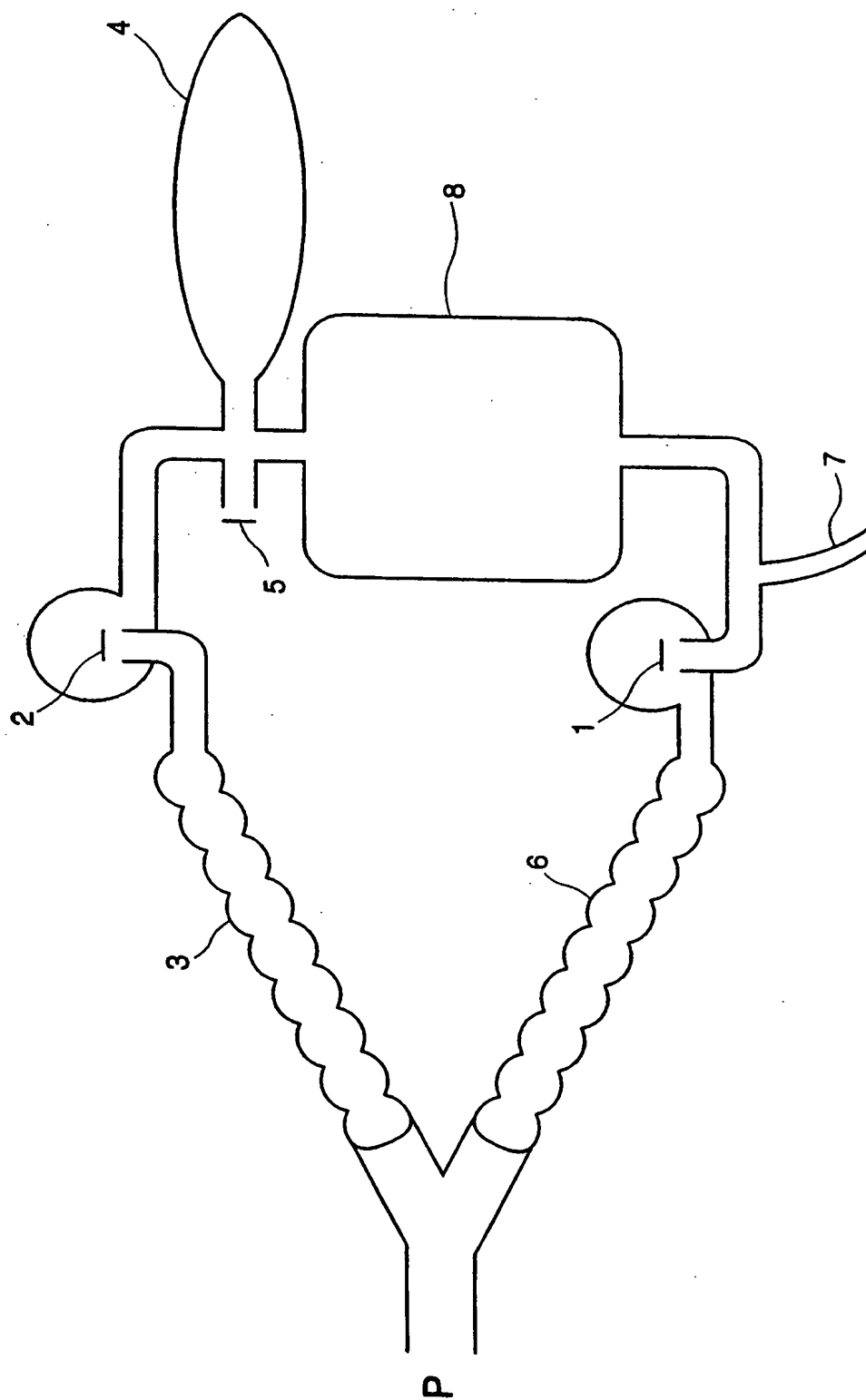


FIG 2

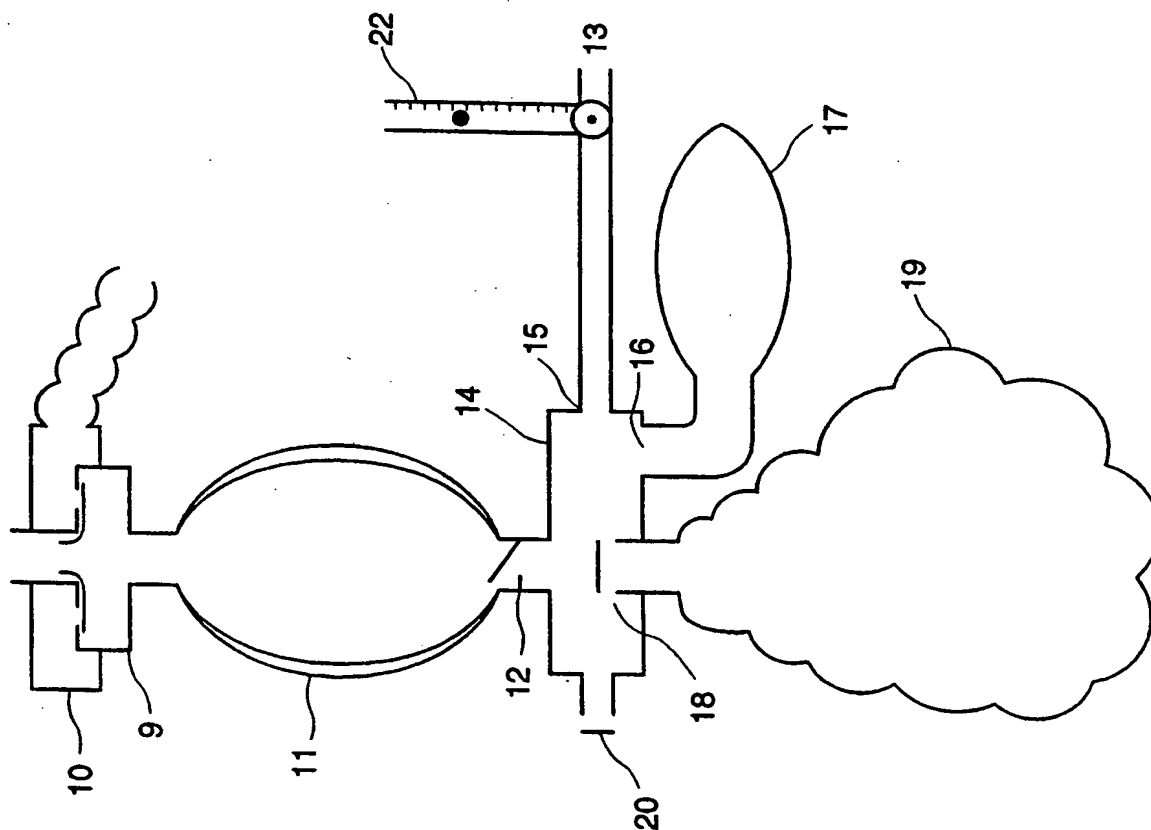


FIG 3

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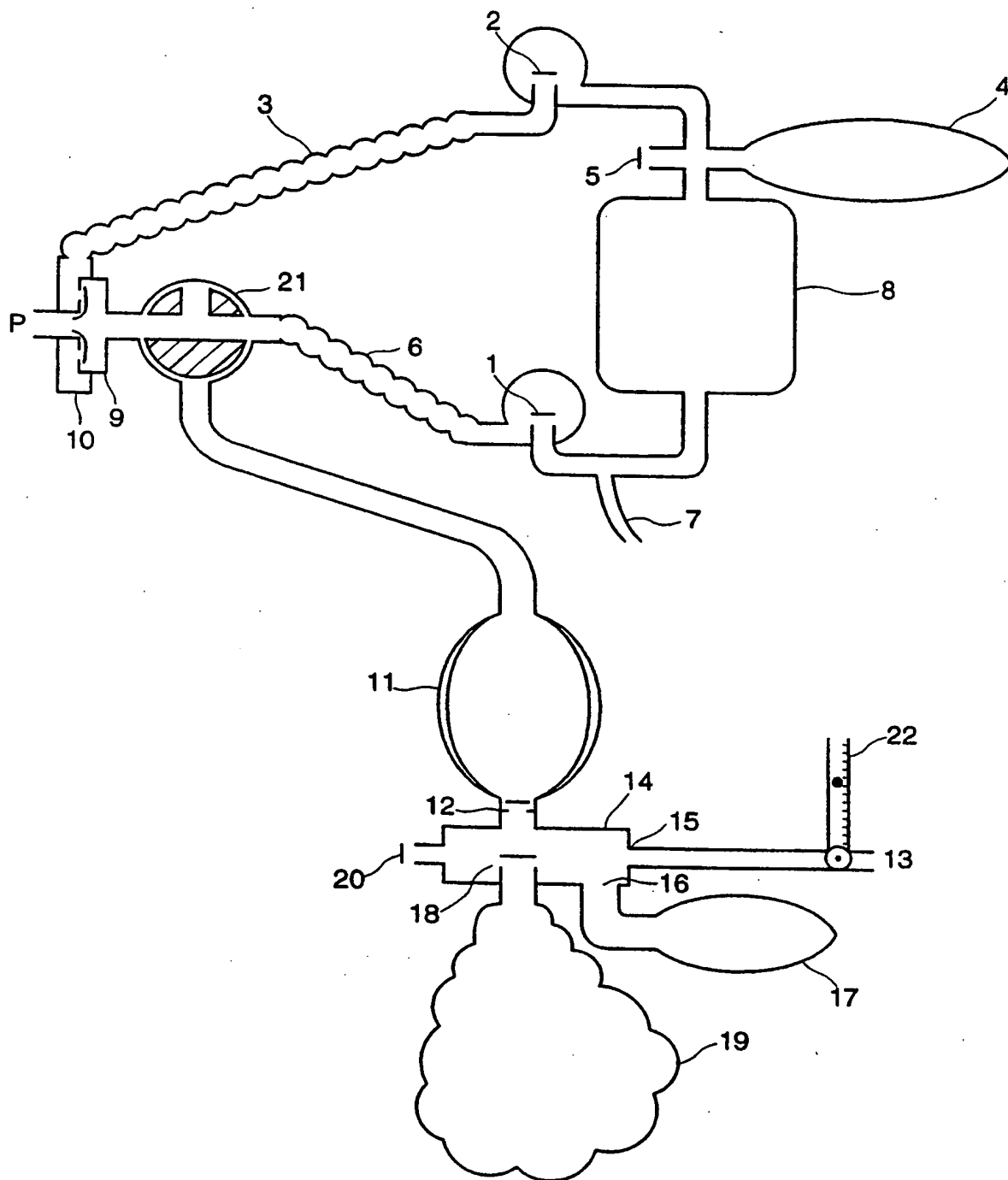


FIG 4A

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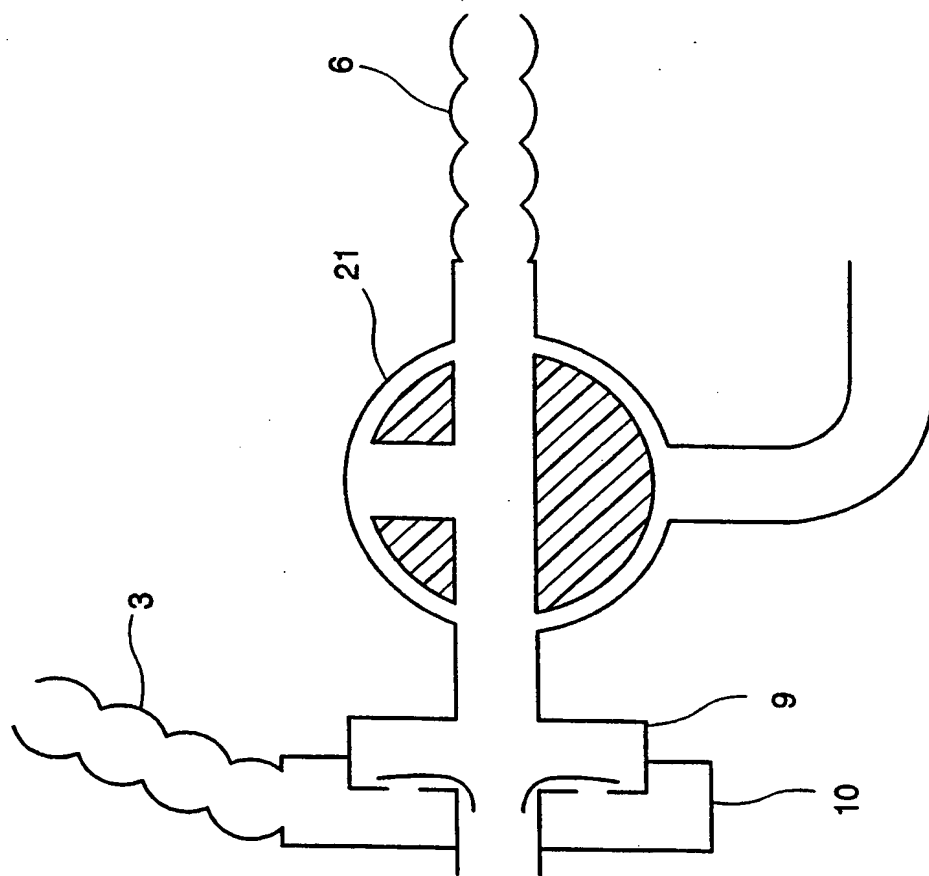


FIG 4B

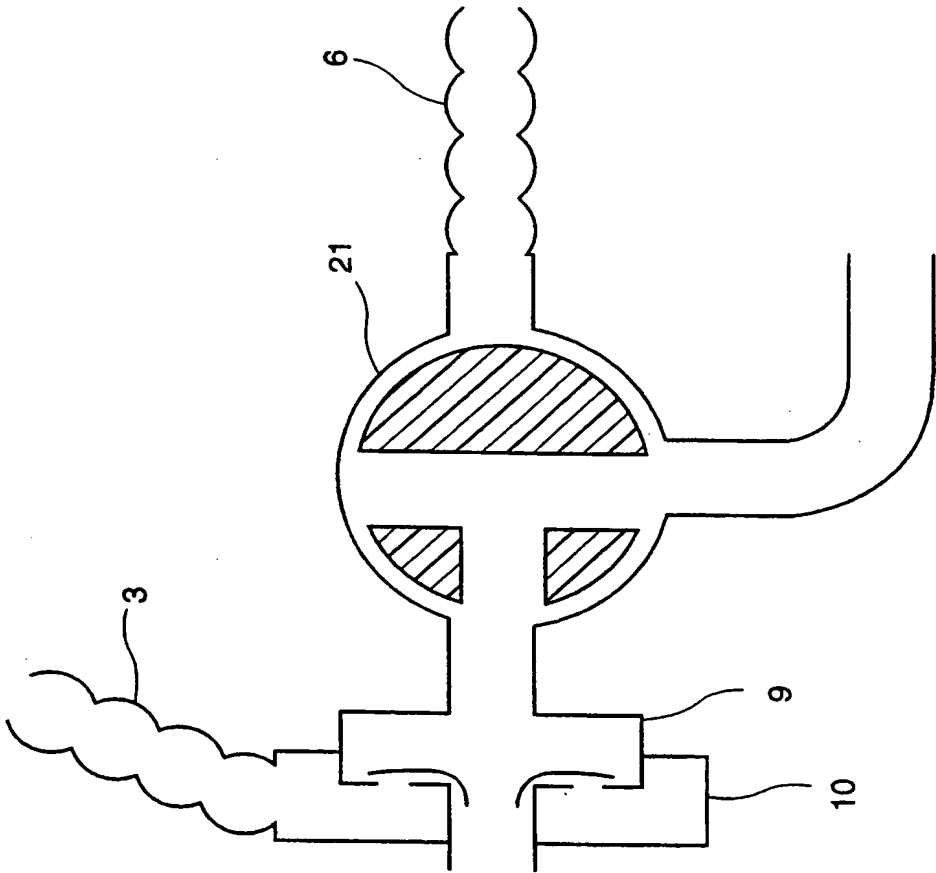


FIG 4C

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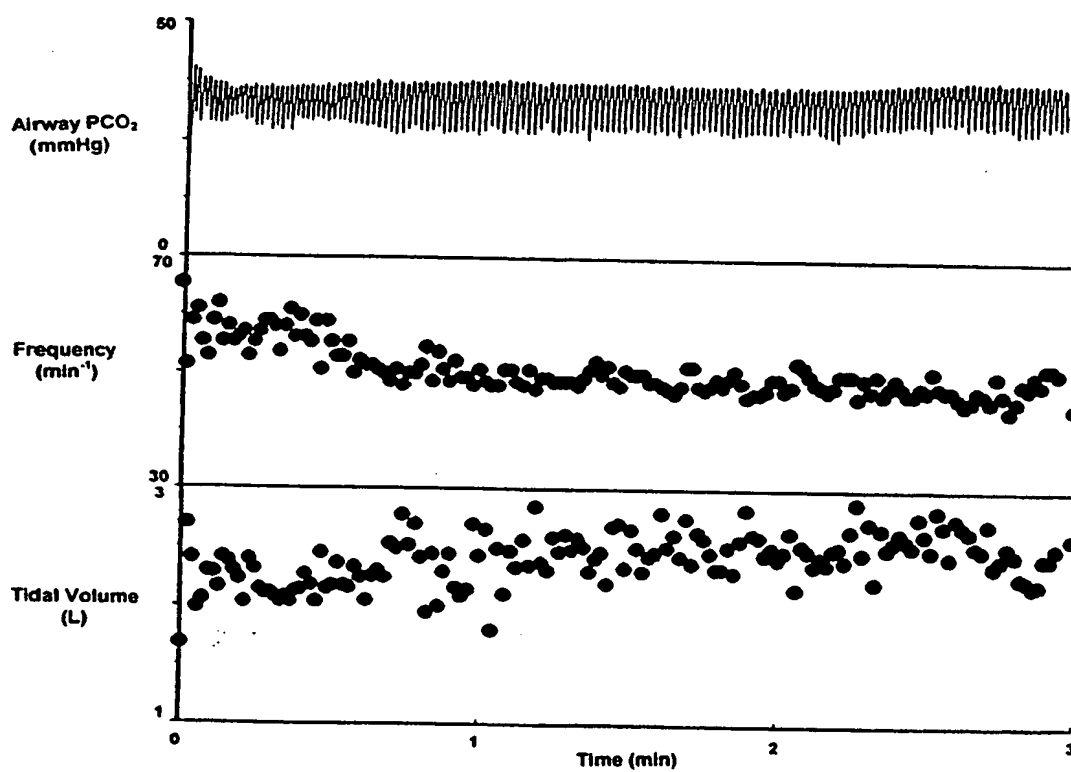


FIG. 5

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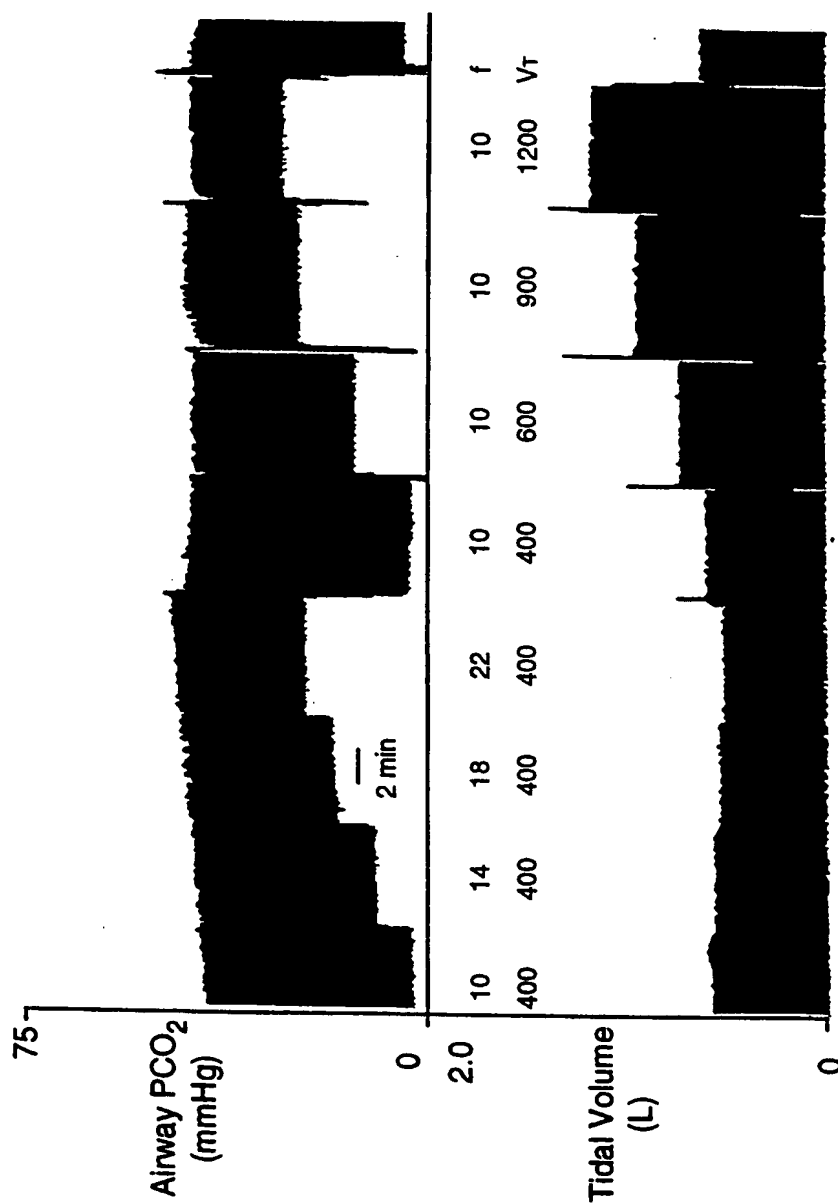


FIG 6

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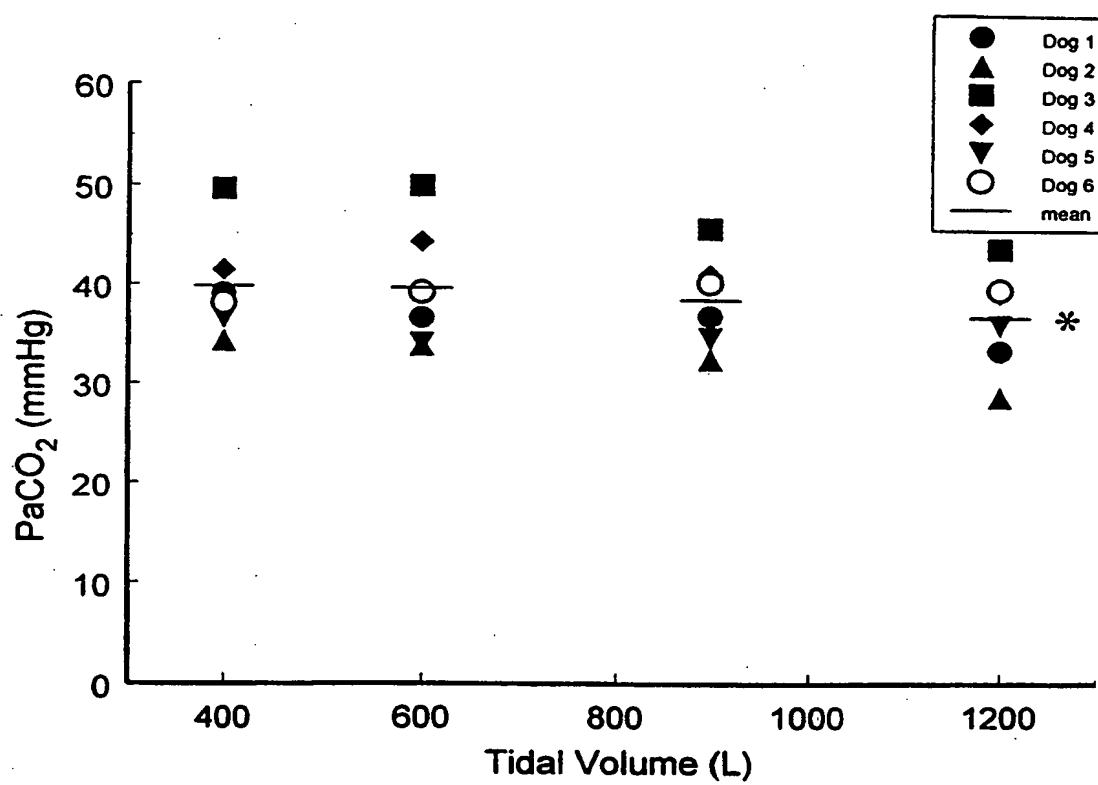


FIG. 7A

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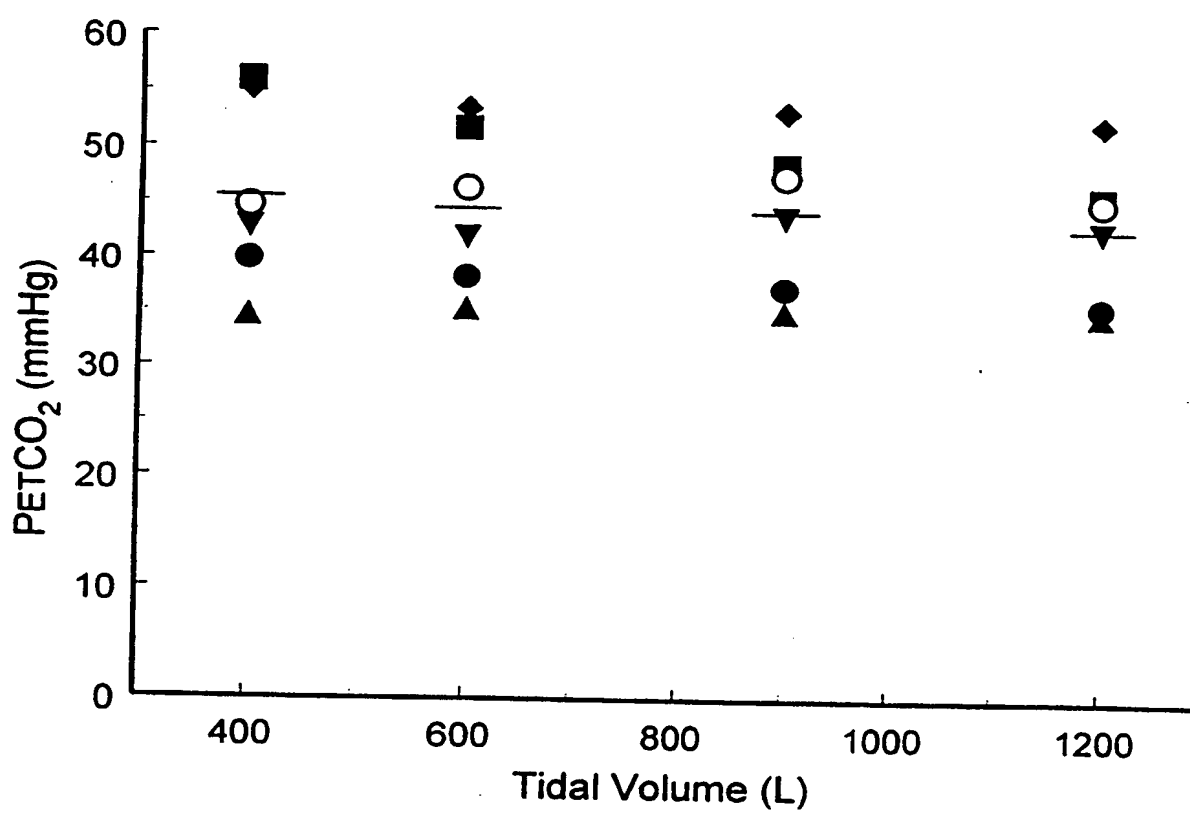


FIG. 7B

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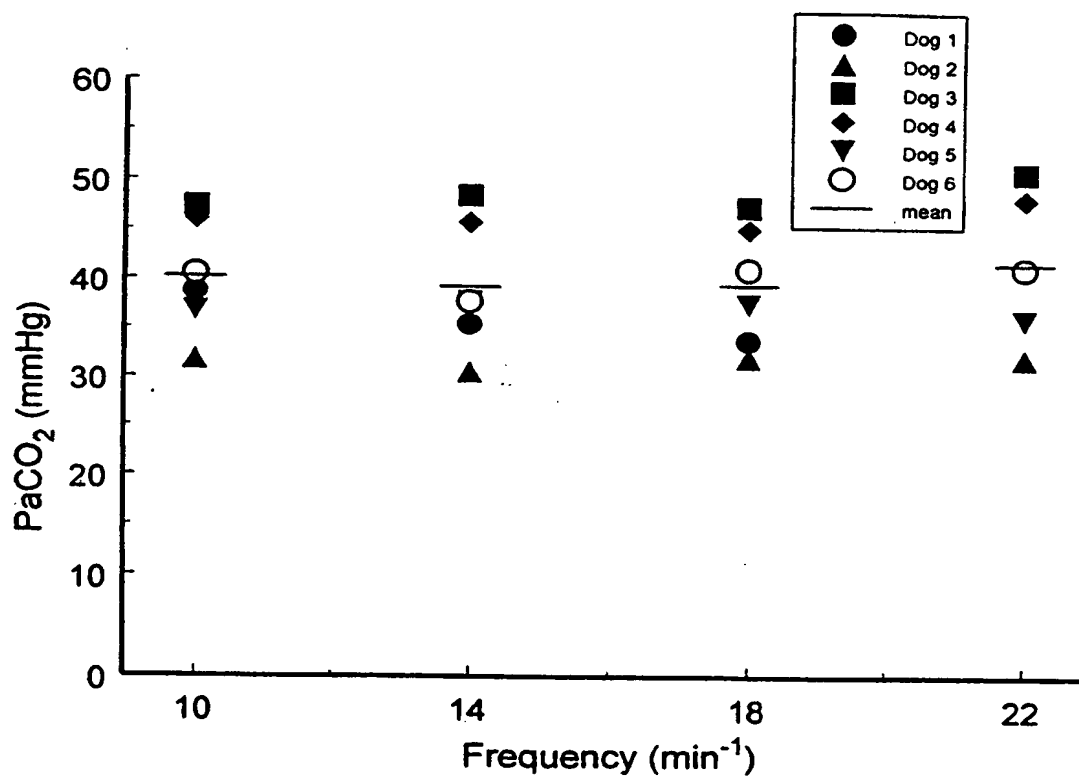


FIG. 8A

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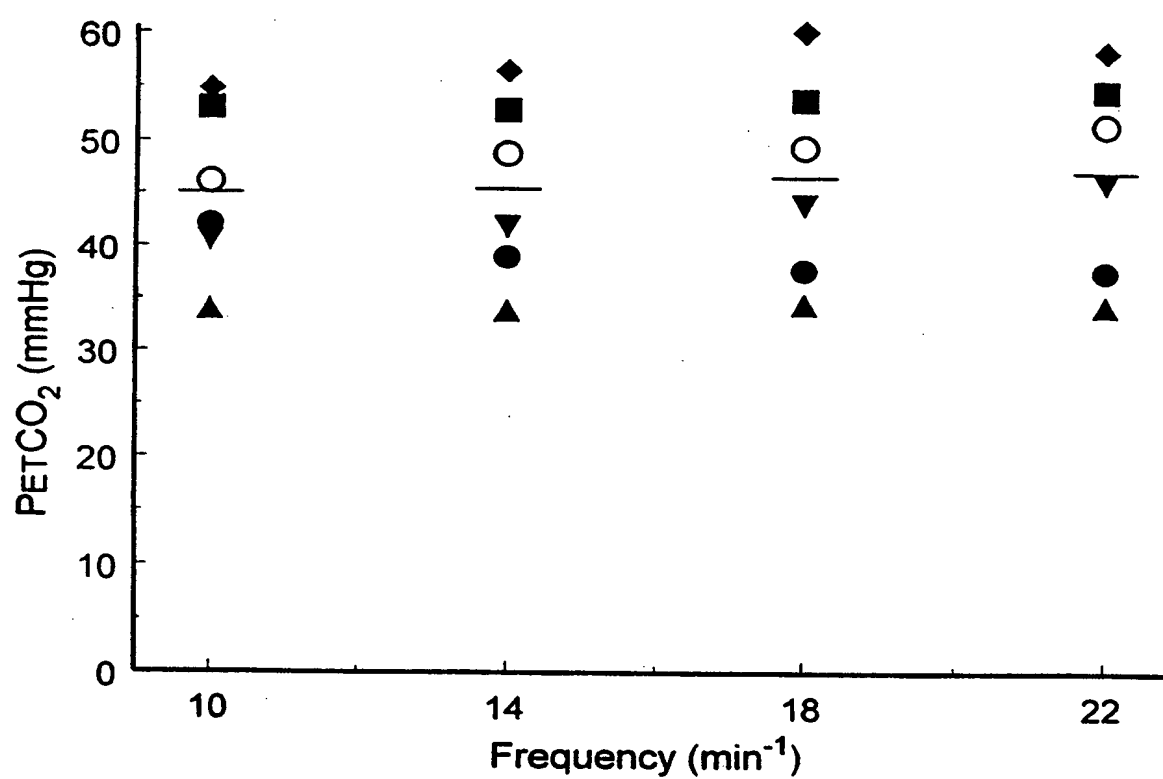


FIG.8B

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INTERNATIONAL SEARCH REPORT

International Application No

PCT/CA 97/00186

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 A61M16/00 A61M16/12

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 A61M

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 320 093 A (RAEMER DAN) 14 June 1994 see column 9, line 37 - line 50; claim 1 see column 3, line 47 - line 64	1-3
A	see column 4, line 39 - line 55	4-7
A	US 4 188 946 A (RAYBURN ROBERT L ET AL) 19 February 1980 see abstract; figures	4-7
A	WO 96 36385 A (JACOB & ALLARD AB ; JACOB PETER (SE); ENGLESSON SOEREN (SE)) 21 November 1996 see page 8, column 2	4-7

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents :

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Date of the actual completion of the international search

19 November 1997

Date of mailing of the international search report

02.12.97

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Authorized officer

Villeneuve, J-M

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA 97/00186

Box I Observations where certain claims were found unsearchable (Continuation of Item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☒ Claims Nos.: 8-11
because they relate to subject matter not required to be searched by this Authority, namely:
Rule 39.1(iv) PCT - Method for treatment of the human or animal body by therapy
2. ☐ Claims Nos.:
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:
3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of Item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest.
- ☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/CA 97/00186

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5320093 A	14-06-94	AU 9167591 A WO 9211052 A	22-07-92 09-07-92
US 4188946 A	19-02-80	US 4320754 A	23-03-82
WO 9636385 A	21-11-96	AU 5786096 A SE 9501792 A	29-11-96 16-11-96

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